

would readily burn in the air, and, while exhibiting the silicon bands, it would also display the lines of hydrogen, particularly the C, F, and H lines, the red C being the most conspicuous. Further observations on this spectrum are desirable, and the hydrogen lines should be particularly looked for; but on the whole I am inclined to believe that Mr. Lundström's deduction as to the origin of the "blue flame" being caused by silicon is substantially correct, if it be understood that the silicon is in combination with hydrogen. Many of the lines and bands in the Ulfshytte spectrum, which have not been identified, have been observed in the Crewe spectra; but their origin still remains a mystery.

"On the Variable Stars of the  $\delta$  Cephei Class." By J. NORMAN LOCKYER, C.B., F.R.S. Received November 9, —Read November 21, 1895.

*Introductory.*

Professor E. C. Pickering, in his classification of the variable stars, which is based on a study of the light curves,\* recognises two classes of variables having short periods. His Class IV includes those variables, exemplified by  $\delta$  Cephei and  $\beta$  Lyræ, in which the light changes are not of very great range, and continue throughout the period. Class V comprises those like Algol in which there is a temporary reduction of light at minimum, produced by the eclipse of the bright star by a relatively dark companion; this explanation has since been established by spectroscopic investigations, which have shown that there is no change in the spectrum at minimum, and that there is an orbital movement of corresponding period.

Both these classes are sharply distinguished from the variables of the Mira type, which form Pickering's Class II. In this class of variables, as in Class IV, the light changes go on throughout the period, but the range of variation is generally much greater, and the periods are reckoned by months instead of days. The variability is associated in this case with a fluted spectrum (Group II), and in a former communication I have shown that the phenomena can be explained on the supposition that there is one swarm (or more) of meteorites revolving in an elliptic orbit round a central swarm; an *increase* of light at maximum occurring at periastron when the number of collisions is greatest.†

It is probable that the variables of Class IV will require further subdivision, when their spectra have been more fully investigated.

\* 'Amer. Acad. Proc.,' vol. 16, p. 17.

† 'Roy. Soc. Proc.,' vol. 43, p. 154, 1887.

Thus, although in regard to the general character of the light changes,  $\beta$  Lyrae must be included in this class, it stands apart from the other members which have so far been spectroscopically observed in having a spectrum which includes a number of bright lines; a detailed study of the spectrum has also shown\* that the lines are periodically doubled, and that part of the variability is due to eclipsing, although the minima are not sharply marked like those of Algol.

Again, in the great majority of the variables of Class IV there is, as a rule, a rapid rise to maximum, followed by a slower descent to minimum, as in the variables of Class II.

Excluding  $\beta$  Lyrae, which, as I shall show, is spectroscopically very different from the others so far examined, it will be convenient to refer to the remaining variables of Pickering's Class IV as those of the  $\delta$  Cephei class, and it is with some of these that the present paper is concerned.

#### *The Kensington Photographs.*

On attempting to continue the investigations of variability to which reference has been made, I found that the available spectroscopic data with regard to the  $\delta$  Cephei class were very meagre, and I therefore determined to investigate the spectra photographically, so far as the means at my disposal would permit. The work was accordingly commenced at Kensington in the early part of 1894, and as some interesting facts have been already brought to light, I have decided, although the research is not yet completed, to communicate them to the Society, more especially as my instrumental means only permit the study of a small number of the stars.

The instruments employed in the inquiry were those named A and B in a previous communication on the "Photographic Spectra of some of the Brighter Stars;"† the former consists of a prism of  $7\frac{1}{2}^\circ$ , placed in front of a 6-inch photographic object-glass, and the latter of a prism of  $45^\circ$  used in conjunction with the same telescope.

The spectra of most of the variables of this class are too faint to be photographed with the great dispersion of B, so that, in some cases, A has of necessity been solely employed. Brief particulars as to the variability of the five stars, the spectra of which have been already photographed, and a statement of the number of photographs taken in each case, are given below.

\* 'Roy. Soc. Proc.,' vol. 56, p. 280, 1894.

† 'Phil. Trans.,' 1893, vol. 184, A, p. 678.

Name.	Magnitude.		Period.	Interval from minimum to maximum.	Photographed with instrument A.	Photographed with instrument B.
	Max.	Min.				
$\gamma$ Aquilæ . . . . .	3.5	4.7	d. h. 7 4	d. h. 2 9	5	
$\zeta$ Geminorum..	3.7	4.5	10 3	5 0	..	
$\delta$ Cephei . . . . .	3.7	4.9	5 9	1 15	3	5
T Vulpeculæ ..	5.5	6.5	4 10	1 7	2	4
S Sagittæ . . . . .	5.6	6.4	8 9	3 10	1	

The spectra generally extend from near F to K.

### *Results of the Preliminary Discussion.*

A careful examination of the negatives has been made by Messrs. Fowler and Shackleton, and five very definite results have been arrived at :—

- (1.) *The spectra of the five variables of this class which have been photographed are practically identical.*

All the spectra are seen to belong to Group III $\beta$  of my classification of the heavenly bodies.\*

It seems, therefore, that as our knowledge of the spectra of variable stars advances, the association of a particular kind of spectrum with a particular kind of variability becomes more and more evident. This is only what we should expect, since I have adduced evidence to show that the possibility of each particular kind of variability must depend upon the state of condensation of the bodies involved.

- (2.) *The five variables in question are stars of increasing temperature.*

The spectra are seen to very closely resemble the spectrum of  $\gamma$  Cygni, and I have already stated the evidence which shows that this star, unlike the sun, is increasing in temperature.†

We have thus revealed to us the fact that these variables, like the other class which I have previously discussed,‡ occupy places on the ascending arm of the temperature curve.

A portion of the spectrum of  $\delta$  Cephei, at the time of maximum, is shown on p. 105, where it is compared with the spectra of  $\gamma$  Cygni and Arcturus. These have been enlarged about ten times from the original negatives taken at Kensington.

\* 'Phil. Trans.,' 1893, vol. 184, A, p. 725.

† 'Phil. Trans.,' 1893, vol. 184, A, p. 718.

‡ 'Roy. Soc. Proc.,' vol. 46, p. 401, 1889.

Taking Arcturus as a representative star of the solar type,\* it will be seen that although the spectra of  $\gamma$  Cygni and  $\delta$  Cephei resemble it in showing a large number of dark lines, they differ considerably from it in point of detail. I shall return to the subject of these differences in a future paper.

On the meteoritic hypothesis, then, the variables of this class are to be regarded as meteor-swarms not yet completely condensed, and this fact may prove of great importance in connexion with explanations of the variability.

- (3.) *There is a general weakening of the continuous spectrum as the light of the star decreases.*

This is shown by the fact that longer exposures are required to photograph the spectra when the variables are near the minima. With equal exposures, the negatives taken near minima are very much less dense than those taken at maximum, and even with the longest practicable exposures, when the highest dispersion is employed, the photographs obtained nearer minimum are relatively feeble. This has been especially noted in the case of  $\delta$  Cephei, one photograph of which was taken exactly at maximum and another only a short time after minimum.

- (4.) *There are no indications of bright-line radiation at the positions occupied by the lines of hydrogen or helium at any part of the period in the case of these variables.*

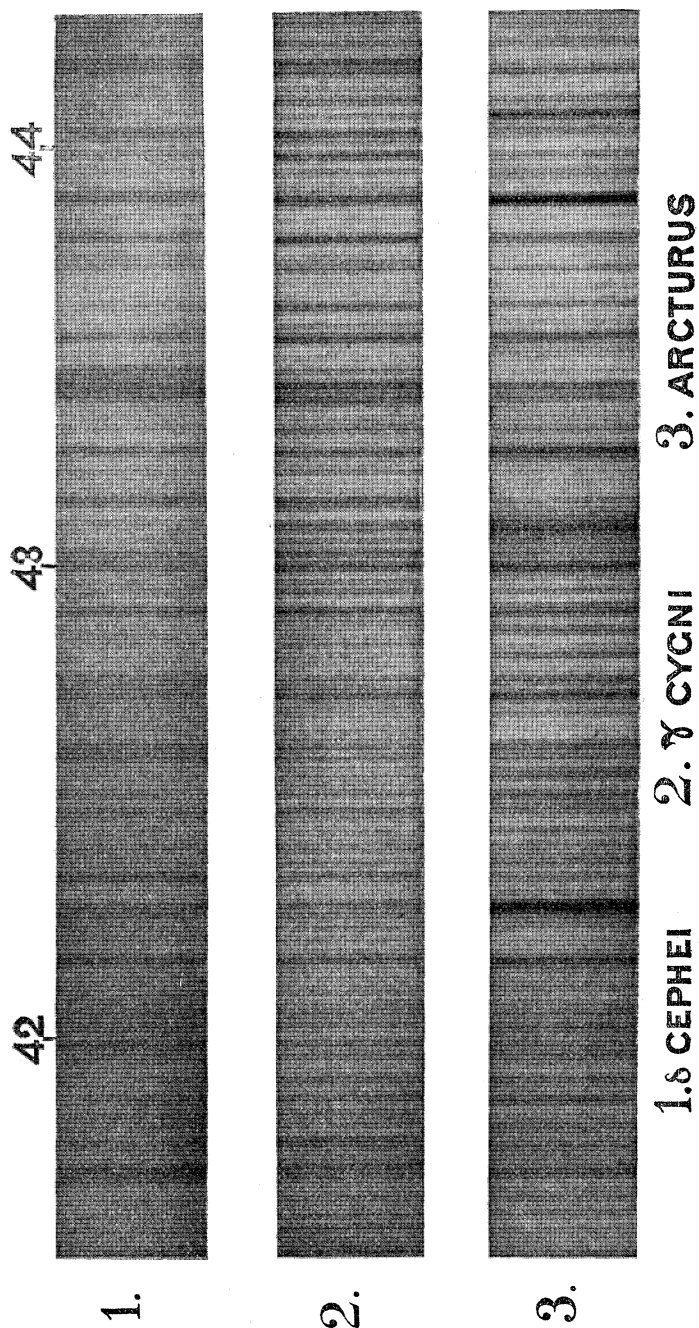
The lines of hydrogen are dark in all cases, and no changes of intensity such as might be brought about by an increased radiation at any time have been found in the photographs. A special search has also been made for bright lines in the positions of the lines of helium and the associated gases, but none have been traced. Since all of these lines occur in the spectra of such stars as Bellatrix, this part of the inquiry was easy—it was only necessary to make direct comparison of the negatives.

- (5.) *There is no visible doubling of the lines in any of the photographs.*

Unlike  $\beta$  Lyræ, the variables now under consideration show no doubling of any of the lines at any part of the period, so far as the Kensington photographs give any information on the point. The photograph of  $\delta$  Cephei (see fig.), taken exactly at maximum, shows that there is no doubling at the time when such appearances might be expected to be most marked.

Hence, the conditions appear to be entirely different from those which exist in the case of  $\beta$  Lyræ, and on the meteoritic hypothesis the stars are less condensed.

\* 'Phil. Trans.' 1893, vol. 184, A, p. 699.



Since the greater part of the foregoing was written, the results of a photographic study of the spectrum of  $\delta$  Cephei, with special reference to its movement in the line of sight, have been published by Belopolsky.\* Belopolsky differs from me in classing the star as a solar one, although he draws attention to numerous differences between the spectrum of the star and that of the sun.

He also finds, as I have found, that there is probably no change of spectrum corresponding to the light changes, except a general change of intensity.

The photographs discussed in the present paper were taken by Messrs. Baxandall, Shackleton, Butler, and Wardale, between February and June, 1894.

*November 30, 1895.*

#### ANNIVERSARY MEETING.

The LORD KELVIN, D.C.L., LL.D., President, in the Chair.

The Report of the Auditors of the Treasurer's Accounts, on the part of the Society, was presented as follows:—

“The total receipts on the General Account during the past year, including balances carried from the preceding year, amount to £9,356 19s. 6d., and the total receipts on account of Trust Funds, including balances from the preceding year, and the proceeds of the sale of stock, amounted to £5,526 10s. 2d. The total expenditure for the same period, including investments, amounted to £8,404 9s. 6d. on the General Account, and £3,373 17s. 5d. on account of Trust Funds, leaving a balance on the General Account of £904 6s. 10d. at the bankers (which includes £100 Catalogue Account and £259 Water Research Account), and in the hands of the Treasurer a balance of £48 3s. 2d.; leaving also at the bankers a balance on account of Trust Funds of £2,147 10s. 0d.”

The thanks of the Society were voted to the Treasurer and Auditors. The Secretary then read the following Lists:—

\* ‘Imp. Acad. Sc., St. Petersburg, Bull.’ Nov., 1894.

42

43

44

1.

2.

3.

1.δ CEPHEI

2.γ CYGNI

3. ARCTURUS